GASEOUS MONITORING FOR THE INTEGRATED LIFE SUPPORT SYSTEM AT LANGLEY RESEARCH CENTER

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The Integrated Life Support System (ILSS) is an engineering concept and, in fact, a functioning test chamber. It was designed to provide for all the needs of four men, in a safe comfortable atmosphere, for intervals of time up to 90 days without resupply. It is, therefore, a prototype physical-chemical system to support life by reclaiming for reuse water and oxygen. It is the first to completely integrate within a test bed all the components for a closed environmental system, including man.

The Integrated Life Support System was conceived in late 1960 to emphasize the problems of integrating existing subsystems designed to operate at zero gravity. By the summer of 1963, a contract for the construction of an experimental hardware, breadboard-type system was let to General Dynamics, Convair Division. There were no stringent qualifications placed on the component parts because the total system was an experimental design. State-of-the-art hardware was procured and qualified in subsystem integration. Before delivery of the packaged systems, the builder conducted various performance tests, including a man-machine operation. There was limited gas monitoring equipment used in support of these tests. The unit was delivered to Langley Research Center (LRC) in August 1965 where it was installed and brought into operation.

The test bed is an 18-foot-diameter steel chamber arranged into two levels (figs. 1 and 2). The top level is for crew quarters and activities. The lower level is for the life support subsystems. The atmospheric pressure can be controlled from a near-vacuum to a positive pressure. Entrance into the test bed can be accomplished without loss of internal environment

integrity through an airlock. The following are the various subsystems found within and associated with the test bed: thermal control, atmosphere control, water management, waste management, personal hygiene, food management, and finally, instrumentation and control measures (ref. 1).

The thermal control subsystem has three interrelated control circuits to meet the requirements of integrated temperature control. The Brayton nuclear reactor, which appears to be electrical power source of choice, has its waste heat simulated in a heat-transfer circuit. Space radiators are simulated by a low-temperature circuit for heat dissipation. The cabin air environment is maintained by the air circuit. It is worth noting that the heat load and the electric power loading are integral parts of the integration and simulation program.

The atmospheric control system regulates the composition of the cabin atmosphere by regulating water vapor, carbon dioxide concentration, regeneration of o[illegible] removal of trace contaminants, and air circulation within the cabin.

The oxygen regeneration subsystem reclaims all the oxygen in the carbon dioxide g[illegible]erated by the crew and returns it into the cabin. The carbon byproducts are either collected or discharged to the outside. The regeneration subsystem has integrated into it the following components: (a) a carbon dioxide concentration unit for carbon dioxide removal from the cabin air, (b) a Bosch r[illegible]duction unit which converts carbon dioxide and hydrogen to water and carbon, (c) a Sabatier reactor which converts carbon dioxide and hydrogen to water and methane (this unit was planned as a backup unit for the Bosch reactor), and (d) an electrolysis unit which converts water into oxygen and hydrogen; the hydrogen is passed to the reduction units.

Trace atmospheric contaminants are removed by continuously passing a fraction of the cabin air through catalytic burners and charcoal filters. The primary function of the catalytic burner is to oxidize carbon monoxide, hydrogen, and methane. The charcoal filters are in the system to remove higher molecular weight trace gases. There are several fiber glass filters to remove particulates from the air.

The cabin air circulation subsystem functions to maintain crew comfort requirements and heat-transfer requirements. In zero gravity operation, it is to function to prevent concentration gradients from being established.

The water management subsystem consists of two identical evaporation units for normal water recovery from urine, atmospheric water vapor condensate, and used wash water. The waste water is chemically treated at the time of collection to prevent bacterial action and chemical decomposition. Stored water, in conjunction with a standby multifiltration unit, is available for emergencies.

Evaporation is used for primary water purification. It is vaporized by recycling hot air through enclosed saturated wicks. A centrifugal water separator downstream of a condensing heat exchanger removes the water from the airstream and pumps it to holding tanks. The multifiltration unit used employs activated charcoal filters, an ion-exchange resin bed, and bacterial filters.

The waste management subsystem collects and vacuum-dries feces at an elevated temperature; collects and transports urine to the water reclamation subsystem. The dried feces and other wastes are stored in tightly sealed canisters.

The personal hygiene subsystem is relatively rudimentary. An interesting item in this subsystem is the "zero-g-sponge squeezer." It allows loading the sponge with water and also freeing it of water.

Food management also is rather rudimentary. The most important component is the food preparation console which provides hot and cold water by variable metering dispensers.

Finally, the instrument and control system permits safe, controlled, manned, and unmanned operation of the test bed. The functions of the system are to: (1) sense and read out physical quantities (i.e., pressure, flow, temperature, etc.), (2) control variables for stable subsystems operation, (3) failure warning, (4) provide manual and automatic overrides to protect equipment from destruction.

This system is a composite of equipment panels, onboard status panels, a ground control console, linked by a failure warning and alarm system to provide information on the status of the various subsystems.

Gaseous monitoring experience for LRC personnel began in 1963 with the prematurely terminated Manned Environmental System Assessment (MESA I) study at The Boeing Company in Seattle. The men within the chamber were made ill by gaseous contaminants and the test was terminated. This test was the dramatic example needed to make the aerospace community aware that gas monitoring capabilities were necessary and that materials selection was important. A complete stripping and material selection of the space cabin simulator furnishings permitted a successful 30-day test to be carried out in 1964. Gas monitoring equipment at that time did not generally have the sensitivity to detect the low levels of gaseous contaminants that have

been reported to be in simulator environments. In an attempt to overcome this limitation, a Karman detector was built into a process gas chromatograph for the on-line monitoring of MESA II, again at Boeing in Seattle (ref. 2).

In an attempt to illustrate the evolution of the gas monitoring system associated with the ILSS, several related topics will be presented. They are (1) analytic equipment and procedures, (2) sampling, and (3) support activities.

Carbon monoxide and many organic compounds have been reported to be in the atmospheres of space cabins, space cabin simulators, and nuclear submarines. Their concentrations have been low from an analytical chemistry point of view. This does not mean the concentrations are without biological significance. Thus, instrumentation of high sensitivity was sought. In a number of instances the sensitivity requested exceeded that available at the time. Single gas detectors, multicolumn gas chromatographs, and wet chemistry procedures were the chosen pathways.

Single gas monitoring should be a relatively simple matter. There are sensitive detectors for such gases as oxygen, carbon dioxide, and carbon monoxide, but with an added requirement of being able to function equally with two different total gas pressures, there must be some redesigning. The paramagnetic detectors for oxygen monitoring had internal compensation built into them to meet this requirement. Single gas, infrared monitors were chosen to monitor for carbon dioxide in the range 0 to 2.5 percent, and for carbon monoxide in two ranges, 0 to 50 ppm and 0 to 100 ppm.

The lower range necessitated redesign and increased cell length. The carbon monoxide maximum concentrations were chosen to coincide with the Threshold Limit Value of the American Conference of Governmental Industrial Hygienist and submarine experience.

A general purpose thermal conductivity detector, process gas chromatograph was secured to monitor various stages of gas processing in the oxygen reclamation subsystem and also the gaseous environment. The sampling streams are fed into the chromatograph from the transfer panel. Ten sampling streams are fed into the chromatograph from the transfer panel. By connecting a flexible tube to a sampling port, any additional location within the test bed may be sampled. This process chromatograph has four columns. Two identical columns are to strip out the higher molecular weight organic compounds and retard water vapor. Carbon dioxide is retained and eluted from one column. The last column is used for separating hydrogen, oxygen, nitrogen, methane, and carbon monoxide.

Two samples are taken simultaneously from each sample stream: one 300 microliters and the other 3 milliliters in size. The smaller sample is used for gases in high concentration. The larger sample is used for the low concentration gases. The chromatograph is programed to handle the samples in sequence at intervals of 10 minutes. A complete sampling cycle requires 200 minutes. The following table illustrates the sampling sequence, the programed calibration ranges for each gas, and sample stream.

PROCESS GAS CHROMATOGRAPH, CONCENTRATION RANGES

Stream	Sample inject	H_2O	CO_2	H_2	O_2	N_2	CH_4	CO
1	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 0.1
2	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	0 - 5	0 - 5	0 - 5	0 - 5
3	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
4	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
5	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
6	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 0.1
7	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
8	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
9	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 5
10	Small	-	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100	0 - 100
	Large	0 - 10	0 - 5	0 - 5	-	-	0 - 5	0 - 0.1

NOTE: Concentrations in percent by volume.

The Karman detector gas chromatograph that was mentioned earlier was further modified as the result of the experience acquired during the MESA II test. The concentrations of the "permanent" gases so overloaded the electrometer system that subsequent peaks were undetected. The chromatograph was modified and programed to shunt these gases out of the detector-gas stream. This modification permits the Karman process chromatograph to function as a trace contaminant detector. The plumbing to the trace analysis chromatograph allows it to be used in two ways. It may be operated independent of the process chromatograph for atmospheric sampling. It may be operated in conjunction with the process gas chromatograph for trace analysis in the process streams of the various subsystems. The trace analysis chromatograph has been calibrated for certain organics that have been reported in the aerospace and submarine literature. Listed in the following table are the compounds and the concentration ranges for which the instrument was calibrated.

Compound	Range in ppm
Acetone	0 - 10
Methanol	0 - 20
Benzene	0 - 10
Trichloroethylene	0 - 10
Methane	0 - 120
Carbon monoxide	0 - 30
Hydrogen	0 - 300

Methane could be a major contaminant arising from man and machine. Thus, analytic information on methane and all other hydrocarbons would be highly useful. A total hydrocarbon analyzer is used to give us this additional information.

The total hydrocarbon analyzer is a flame ionization detector device. Col. Thadeus Domanski (USAF) in cooperation with LRC personnel decided that a first approximation to organic materials in the atmosphere could be had by determining the total hydrocarbons. Methane equivalents were chosen as the means of expressing this concentration. The difference between this value and the methane value from the Karman gas chromatograph would be the approximate concentration of the contaminants. This instrument operates on-line and gives real-time information. These results have more immediate meaning than those that have been generated by trapping procedures.

Construction of instrumentation can pose unexpected problems. One instrument that was delivered to Langley Research Center and one constructed at Langley were plumbed with copper tubing. There was sufficient surface to catalyze the conversion of organic compounds. This resulted in divergent readings from several monitoring locations. Replumbing with stainless steel tubing corrected this problem. Helium carrier gas contamination posed a problem in the early stages of putting the chromatographs into operation. Helium delivered in tank cars was bottled and used. It was discovered that the water vapor concentration was sufficient to poison the chromatograph columns. Assayed helium with a guaranteed analysis of 99.999 percent helium was substituted.

Reliable sampling of gases from the various locations in the test bed continues to be a problem. Many of the deficiencies are recognized. A problem not recognized by many who have not had to sample organic gas mixtures is the length of tubing (surface exposure) to which the gases

are exposed. We have 37 lines about 40 feet long running from the test bed to a transfer or patchpanel. This surface exposure poses a sampling uncertainty and an analytical nightmare. Although care has been taken to prevent condensation within the tubes, there are thermal gradients and associated adsorption and desorption sites. Thus, the sample analyzed has a high probability of not being the one drawn originally. Efforts are being directed toward a solution of this sampling problem. The transfer or patchpanel is an interconnecting link between the test bed and the atmospheric monitoring areas. It was designed to simplify sample stream selection and delivery to the analytical equipment, cryogenic sampling system, and the wet chemistry area.

The cryogenic sampling system was designed for LRC by Atlantic Research Corporation. It permits trapping samples at various low temperatures with regulated flow rates. The sample trap may be easily replaced through the use of quick disconnect couplings. Samples are drawn through the stainless steel traps at a reduced pressure of 400 torr in an attempt to reduce oxygen trapping. With the removal of the traps from the cryogenic traps they begin to warm, the pressure increases. For safety purposes the pressure is kept within the safe pressure range of the bottle. Temperature changes, pressure changes, and release may alter the sample before analysis.

The wet chemistry area was established to analyze for the more odoriferous byproducts of man and some from the processes. From the results of this work, it was felt that the requirements for automatic

equipment could be established. So far, no equipment has been requested to handle these analyses. The table below lists the compounds monitored and the procedure used to analyze for it.

Compound	Method
Ammonia	a. Acid neutralization (ref. 3) b. Ninhydrin reaction
Sulphur dioxide	Colorimetric (ref. 4)
Hydrogen sulfide	Lead sulfide precipitation (ref. 5)
NO NO_2	Colorimetric (ref. 6)
Mercaptans	Colorimetric (ref. 7)

Additional support equipment is immediately available to assist in identifying contaminants. This exists in two F and M 810 gas chromatographs: an infrared spectrophotometer with a 10-meter cell, and a research gas analysis laboratory. In other parts of LRC, additional support equipment is found in the form of microwave spectrometers and a high-resolution mass spectrograph. These have not been used to any great extent in ILSS support.

The F and M 810 gas chromatographs are two-column, flame ionization detector, general purpose instruments. They are calibrated for a large number of organic compounds reported in the aerospace literature.

The research laboratory has gas chromatography and infrared spectrophotometry capabilities. This laboratory was established by Dr. Robert M. Bethea for comprehensive analytical work. In addition to the analytical

procedures established, a computer program was developed to reduce the time for complete analysis of contaminants.

The complexities of putting a fully integrated life support system into operation are manifested in the time it has taken from delivery and our first closed-door test. A number of open-door tests were performed to check the functioning capabilities of the individual subsystems and the supporting equipment. As a result of these tests, a major subsystem improvement program was started. As the improvements were completed, the subsystems were again evaluated. Completion of improvements and satisfaction with the evaluation results permitted proceeding on to the next step in the testing program, closed-door integrated system operation.

The first closed-door test for the ILSS at Langley Research Center was accomplished during the 7-day period from January 31, 1967, to February 7, 1967. Several major objectives were obtained in this test, one of which was atmospheric monitoring experience with all life support equipment in operation and the hatches closed.

The most significant observation in atmospheric monitoring was the low level of contamination. The baseline for total hydrocarbons before the hatches were closed was 3 ppm (parts per million). After hatch closure, it slowly rose to stabilize at 6 ppm. There was one excursion above this level to a value of 15 ppm. The contaminant control system appeared to remove this unidentified contaminant.

The nonadapted nose is still the most sensitive detector for odors. This was illustrated again in this test. A small mechanical pump used for atmospheric bacteriologic sampling discharged some oil vapors into

the chamber air. The odor was most disagreeable to men who had to enter the chamber. Discontinued use, removal of the pump, and the contaminant control system returned the atmosphere to an acceptable point. None of the analytical equipment detected the material - not even the total hydrocarbon analyzer.

An unplanned contaminant removal system has been in nearly constant use for over a year. Filtered air driven by a powerful blower has kept the chamber flushed out, also preventing accumulation by adsorption and absorption. Many contaminants have been eliminated by preventing admission into the chamber and by materials selection.

We do not have a complete analysis of our contaminants, nor do we know how man will disturb the system. We are preparing to define and attempt solutions of these and other problems of atmospheric contamination in the ILSS.

SUMMARY

The Integrated Life Support System was conceived to study the problems of integrating regenerative equipment designed to operate in a negligible gravitational field. It is the first to fully integrate the three major contributors to atmospheric contamination: man, machine, and materials.

Aerospace literature has been replete with many lists of organic compounds that may have been in space cabins and space cabin simulators. Some of these compounds are real; others are perhaps artifacts of sampling

and sample handling. Nonetheless, the choice of instrumentation for ILSS contaminant monitoring was predicated on the assumption that there might be a problem. Several types of sensitive instrumentation have been employed to monitor this potential problem, the most notable being the total hydrocarbon analyzer. This instrument gives a first approximation of the contaminant problem. The results appear to be more reliable than the results, till now, from more sophisticated instrumentation and sampling procedures. Gas chromatography, infrared and mass spectroscopy, and microwave analysis will give the final definition of the contaminants. Before these instruments can truly be effective in contaminant definition, the problem of sampling and sample handling will have to be solved.

The limited contaminant problem experienced during the 7-day closed-door test of the ILSS illustrates the effectiveness of the contaminant removal system. A fact which should not be overlooked in contaminant removal in the ILSS was the unplanned but virtually continuous forced air flushing of the chamber for 1 year. The nonadapted nose is still the most sensitive detector for odoriferous compounds in small quantities. During the test procedure, a disagreeable odor was observed. A microbiological sampling pump had been in operation. The air contaminant had not been detected by the analytical instrumentation. Discontinued use and removal of the pump coupled with the trace contaminant removal system discharged the odor within 8 hours.

Much data are yet to be derived from this test chamber on man, machine, and material interactions.

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LIFE SUPPORT SYSTEM TEST BED
INTERIOR

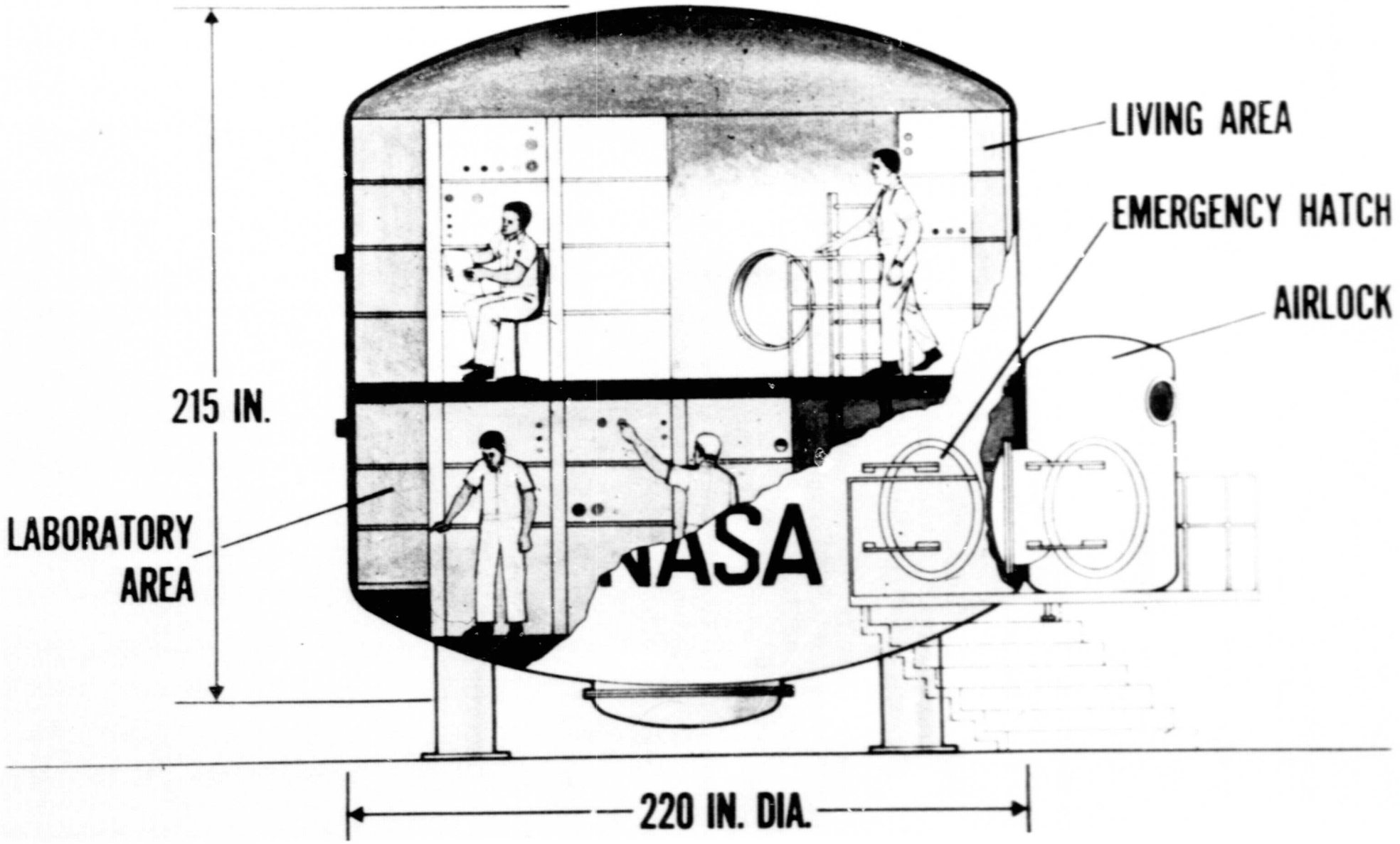

Figure 1

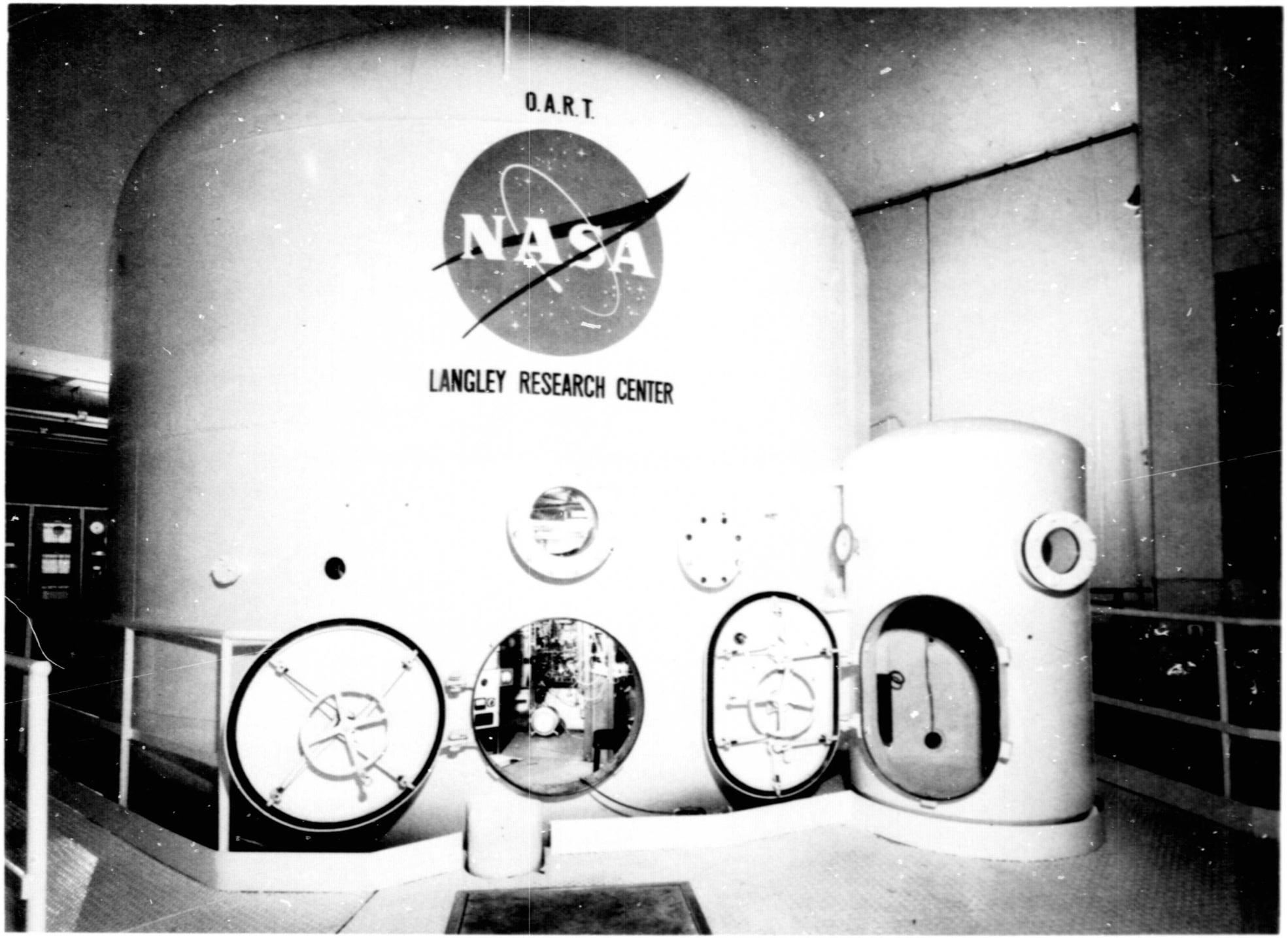

Figure 2